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REPORT 2931

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# NUCLEAR LUNAR LOGISTICS STUDY

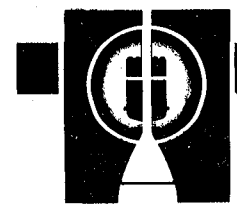
PRESENTATION 18 JULY 1963 • HUNTSVILLE, ALABAMA

RESTRICTED DATA

ATOMIC ENERGY ACT OF 1954

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ROCKET ENGINE OPERATIONS-NUCLEAR

AEROJET-GENERAL CORPORATION / AZUSA, CALIFORNIA

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MSC-63-376  
Report 2931

AGC. 9727. 79 (4014)

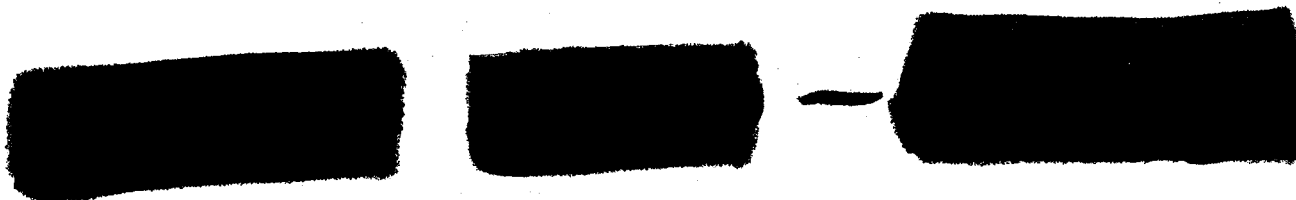
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### INTRODUCTION

This document has been prepared to incorporate all presentation aid material, together with some explanatory text, used during an oral briefing on the Nuclear Lunar Logistics System given at the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, on 18 July 1963.

The briefing and this document are intended to present the general status of the NERVA nuclear rocket development, the characteristics of certain operational NERVA-class engines, and appropriate technical and schedule information. Some of the information presented herein is preliminary in nature and will be subject to further verification, checking and analysis during the remainder of the study program. In addition, more detailed information will be prepared in many areas for inclusion in a final summary report.

This work has been performed by REON, a division of Aerojet-General Corporation under Subcontract 74-10039 from the Lockheed Missiles and Space Company. The presentation and this document have been prepared in partial fulfillment of the provisions of the subcontract.



THE NERVA FLIGHT TEST ENGINE

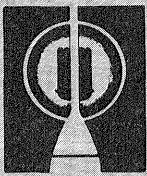
From the inception of the NERVA program in July 1961, the stated emphasis has centered around the demonstration of the ability of a nuclear rocket to perform safely and reliably in the space environment, with the understanding that the assignment of a mission (or missions) would place undue emphasis on performance and operational flexibility. However, all were aware that the ultimate justification for the development program must lie in the application of the nuclear propulsion system to the national space objectives.

A full-scale mock-up of the flight test NERVA engine is shown on the facing page. The engine is about 22-1/2 feet long from the vehicle interface to the exit plane of the exhaust nozzle. The pressure vessel is 56 inches in diameter and the maximum envelope is about 8 feet across the pressurization spheres. It is estimated to weigh about 14,000 pounds, to develop about 56,000 pounds of thrust and to achieve a specific impulse of about 756 sec. It consists of several major systems: the nuclear system (including core, reflector, shield); the propellant feed system (including turbo-pump and lines and valves); the thrust chamber assembly (including nozzle, pressure vessel, gimbal, upper and lower thrust structure); the engine control system; the pressurization system; and the destruct system.

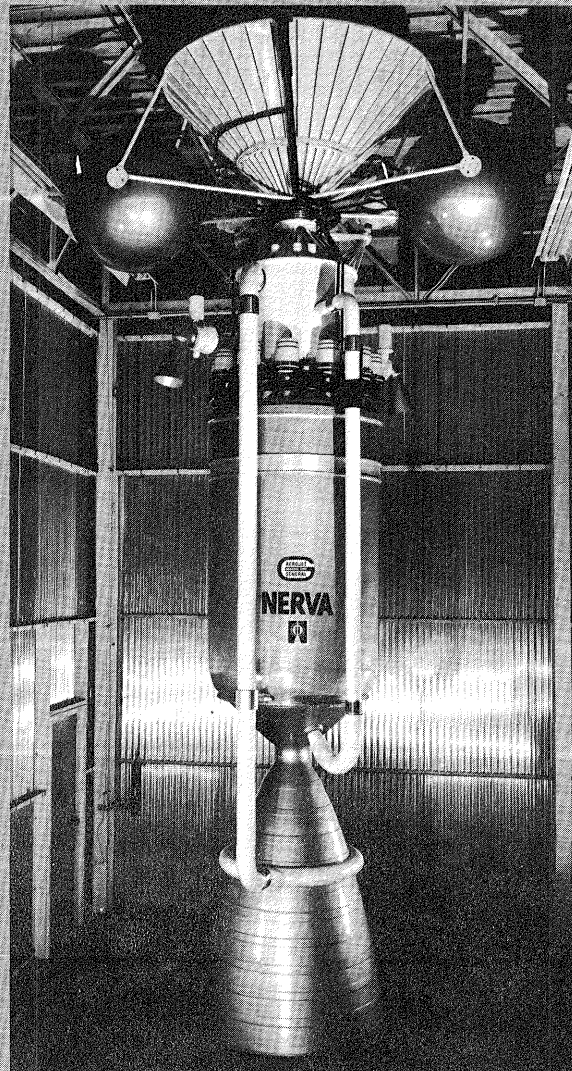
The engine operates on the hot-bleed cycle concept, so-called because of the position and hence temperature at which hydrogen is extracted to provide turbo-pump drive fluid. Hydrogen enters the engine through the tank shut-off valve, passes through the pump, and is ducted to the nozzle where it passes through the tube bundle regeneratively cooling the nozzle. It then passes up inside the pressure vessel through the reactor reflector, shield, and down through the core and out the nozzle producing the thrust. About 4% of the total flow rate is bled off as the hydrogen leaves the reactor (at about 4000°R) for turbo-pump drive. This bleed flow is diluted with some of the relatively cool hydrogen directly from the reactor inlet plenum to a temperature of about 1750°R, suitable for turbine inlet conditions.

Tentative development goals for the NERVA flight test engine include 1200 seconds duration, and capability for two restarts.





## **NERVA MOCKUP**

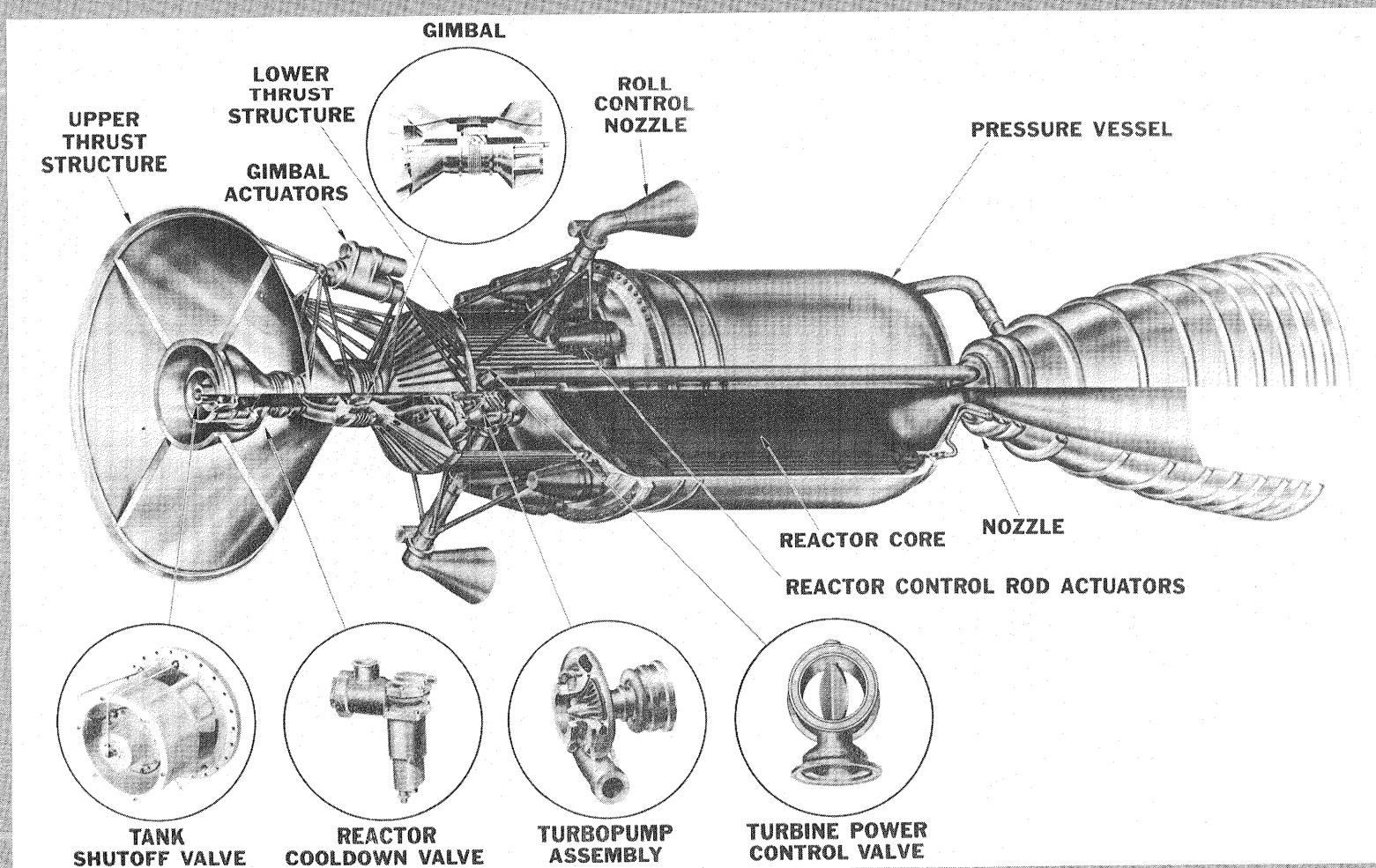






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# UNCLASSIFIED NERVA ENGINE

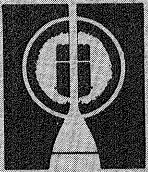


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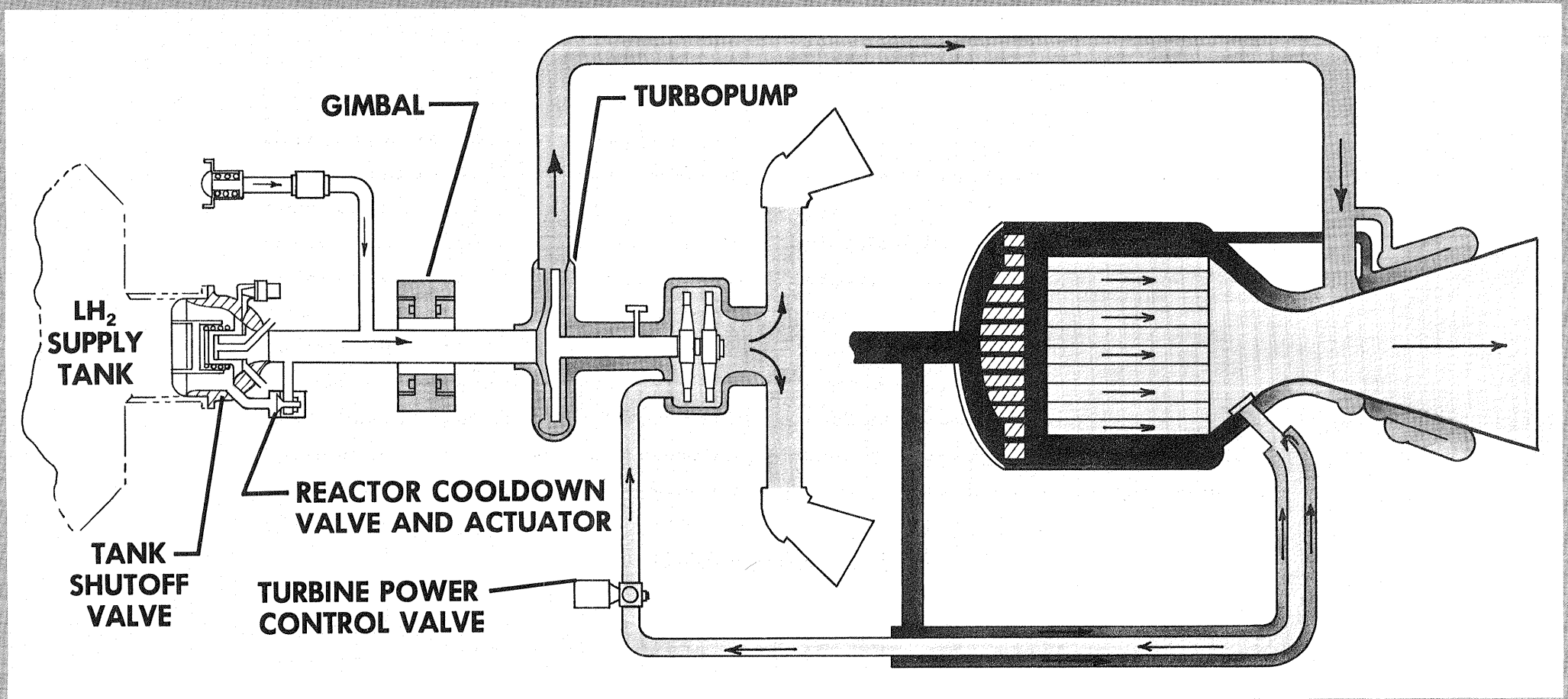
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# PROPELLANT FEED SYSTEM FLOW DIAGRAM

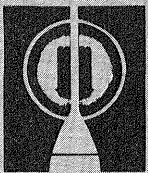


### NERVA STATUS SUMMARY

In July of 1963, most of the problems associated with the development of NERVA have been identified and a solution has been demonstrated for many of them, and a solution is now evident for the remainder. However, one significant obstacle pacing the development at present is concerned with the mechanical design of the reactor. Pending solution of the reactor mechanical design, only limited procurement and development of non-nuclear engine components and subsystems is being permitted and such development is restricted to so-called "critical items," that is, those critical to engine or reactor operation or test. Thus, for example, development of the propellant feed system is proceeding, but only cursory effort is being devoted to the thrust structures or thrust vector control system.

Some of the critical engine items are further illustrated in the following few charts followed by the support equipment items and facilities.





## **NERVA STATUS SUMMARY**

- **NUCLEAR SUBSYSTEM**  
STRUCTURAL INTEGRITY OF REACTOR REQUIRES VERIFICATION
- **PROPELLANT FEED SYSTEM**  
ALL COMPONENTS IN DEVELOPMENT
- **THRUST CHAMBER ASSEMBLY**  
PRESSURE VESSEL AND NOZZLE IN DEVELOPMENT
- **ENGINE CONTROL SYSTEM**  
CONSIDERABLE ANALYSIS AND SIMULATION IN PROGRESS — MANY COMPONENTS IN DEVELOPMENT
- **PRESSURIZATION SYSTEM**  
LIMITED DESIGN AND ANALYSIS BEING CONDUCTED
- **DESTRUCT SYSTEM**  
PRE-OPERATIONAL AND POST-OPERATIONAL DESTRUCT SYSTEM TESTING IN PROGRESS — ANTI-CRITICALITY (ACTIVE AND PASSIVE) BEING EVALUATED
- **SUPPORT EQUIPMENT SYSTEM**  
MAIN SUBSYSTEMS IN FABRICATION  
CONCEPTUAL DESIGN OF CHECKOUT SYSTEMS IN PROGRESS
- **FACILITIES**  
ALL MAJOR DEVELOPMENT TEST FACILITIES UNDER CONSTRUCTION

## NERVA REACTOR

An isometric drawing of the NERVA experimental reactor is shown in the accompanying chart. This configuration is based on the KIWI-B4 LASL concept and technology and there is an extensive background of data and information available regarding this reactor going back to the first reactor in the KIWI test series, the KIWI-A tested in July of 1959. The reactor is made up of a core fabricated from a number of hexagonal, uranium-loaded, graphite fuel elements containing the hydrogen flow passages. The cylindrical beryllium reflector surrounds the core and a lithium hydride shield is mounted on the forward end to provide a significant reduction in radiation reaching the propellant tank and engine components mounted forward of the shield.

The neutronics are well understood, the physical properties of the materials are well known, the fuel element fabrication process has been developed, the controlled start-up has been demonstrated, and methods have been found for protecting the fuel elements in the hydrogen environment. However, as evidenced in the most recent KIWI-B tests, there is a difficult structural problem requiring solution - a mechanical design to provide structural integrity in a unique internal aerodynamic and thermodynamic environment. As a result of the continuing reactor problem, the industrial contractor has been invited to participate more fully in the solution of the mechanical design problem and for this effort the initial NERVA ground rule requiring utilization of KIWI technology and configurations has been modified. Back up reactor structural designs are being evaluated, and one or two of the more promising will undergo further analysis and design prior to December of this year, when a decision will be made regarding fabrication and test of the back-up reactor. .

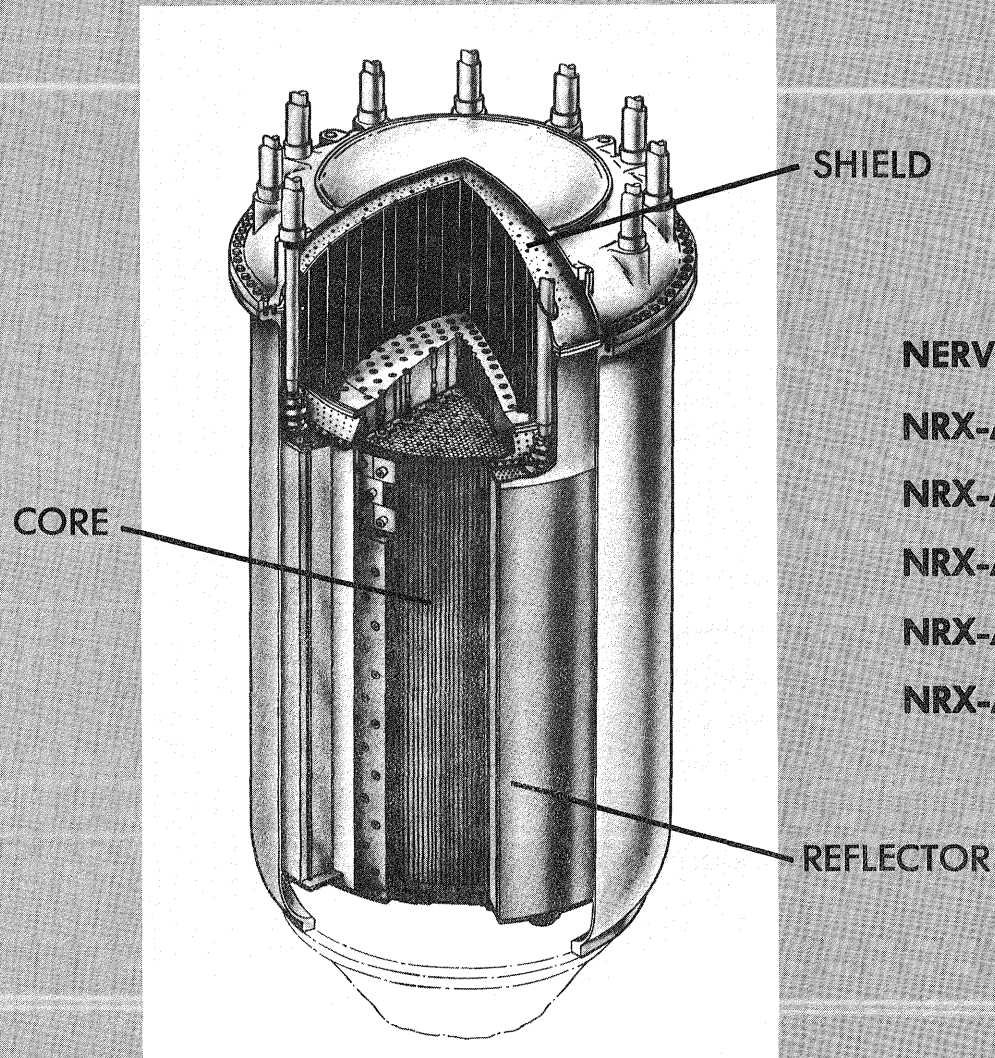




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## REACTOR ASSEMBLY



### NERVA REACTOR ASSEMBLY

NRX-A1	10-5-63	COLD FLOW
NRX-A2	3-7-64	HOT FLOW PARTIAL POWER
NRX-A3	6-6-64	HOT FLOW PARTIAL POWER
NRX-A4	8-1-64	SAME AS A3 WITH RESTART
NRX-A4S	10-3-64	FULL POWER

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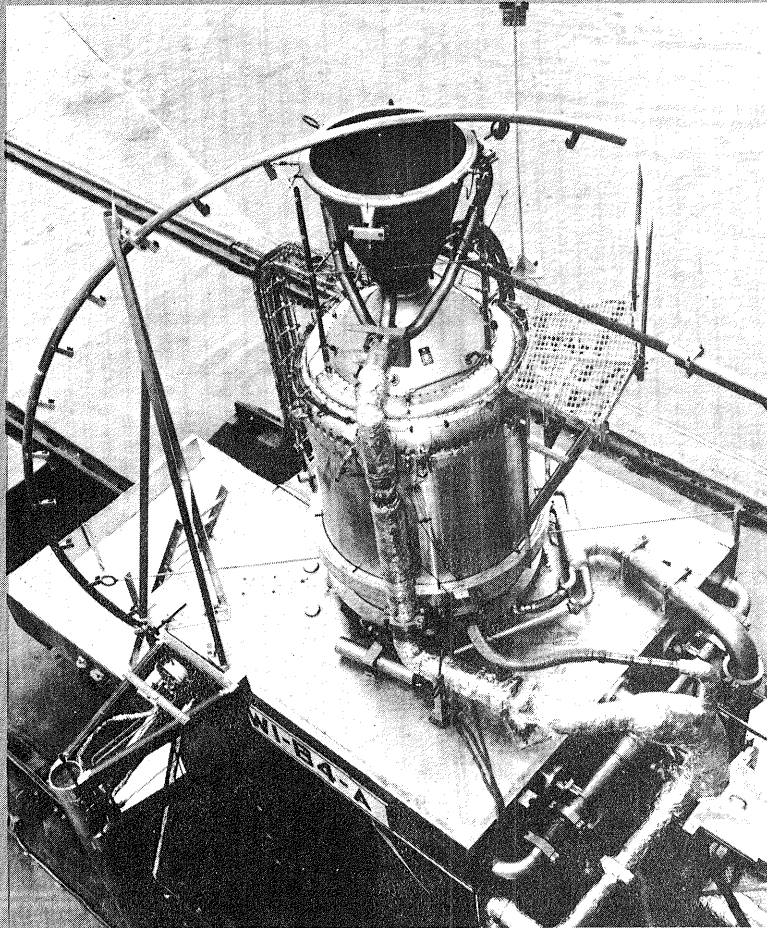
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# REACTOR ASSEMBLY



## • KIWI TEST PROGRAM

A 7-4-59

A' 7-8-60

A-3 10-19-60

B-1A 12-7-61

B-1B 9-1-62

B-4A 11-30-62

B-4A 5-15-63



### NERVA PROPELLANT FEED SYSTEM

The propellant feed system basically consists of the tank shutoff valve, reactor cooldown valve, turbopump, turbine power control valve, and associated check valves and lines.

The tank shutoff valve is a two position valve (normally closed), and actuated by a gas piston with a spring return. The valve is mounted directly on the tank outlet through the use of a remote actuated disconnect coupling.

The cooldown valve is two-position (normally closed), and actuated by a direct current electric motor. This valve allows propellant from the tank to bypass the closed tank shutoff valve.

The turbopump assembly, shown on the opposite page, consists of a mixed-flow centrifugal type pump directly coupled to a multistage gas turbine. The drive shaft is supported by antifriction bearings which are contained within the bearing housing. Both roller and ball type bearings are used and liquid hydrogen is used for lubrication and cooling.

The turbine power control valve is used to regulate turbopump speed. A butterfly type valve is used which is pneumatically actuated through a servo-mechanism. Valve position is controlled by the engine programmer.



# TURBOPUMP ASSEMBLY

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- DESIGN CRITERIA

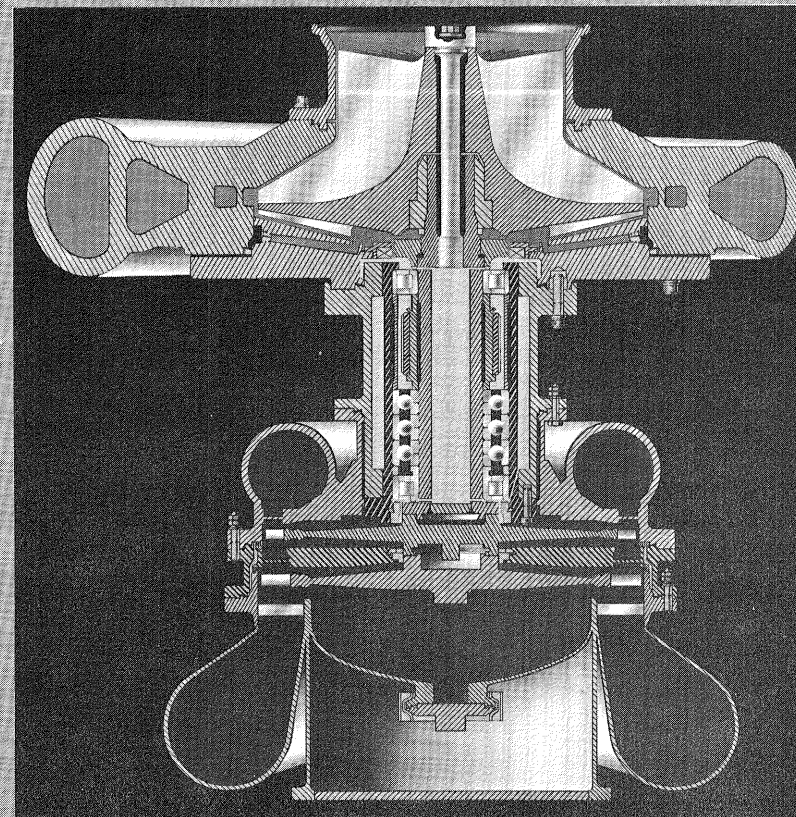
SPEED (rpm)	25,100
PUMP PRESSURE RISE (psi)	1,100
OVERSPEED (rpm)	31,000
CRITICAL SPEED (rpm)	34,000

- TURBOPUMP TEST SUMMARY

NUMBER OF TESTS	TOTAL TIME ACCUMULATED (sec)	MAXIMUM SPEED (rpm)
86	6040	27,800

- BEARING TEST SUMMARY

NUMBER OF TESTS	MAXIMUM SPEED (rpm)
48	16,000
MAXIMUM LOAD (lb)	MAXIMUM CONTINUOUS TIME AT LOAD AND SPEED (min)
3600	11.0



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### NERVA THRUST CHAMBER ASSEMBLY

The NERVA thrust chamber assembly consists of the nozzle, reactor pressure vessel, upper and lower thrust structure, and gimbal.

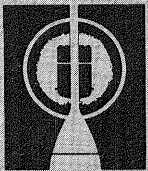
The nozzle shown on the opposite page is of conventional stainless steel tubular construction. Because of the large contraction ratio of the nozzle, the longitudinal loads (which are carried by the tubes in chemical rocket engines) are very high, and a supporting cast aluminum shell must be provided around the tube bundle. Care must be exercised to insure good thermal contact of the shell with the tubes to prevent overheating from thermal radiation induced by the reactor. Special cooling circuits are provided for all material not in direct contact with the main propellant flow, and through all thick sections, such as the flange at the junction between the nozzle and the reactor pressure vessel.

The pressure vessel consists of two units, a cylinder and a forward enclosure. The cylinder is joined to the forward closure and the nozzle with high strength bolts. Ports are located in the closure for control rods, turbine diluent line, and instrumentation.

The thrust structure is made in two parts, an upper structure and a lower structure. The upper structure is a conical stiffened shell, attached to the vehicle tank through a quick disconnect, and attaches to the upper gimbal yoke by bolts. The lower structure is a conical stiffened shell, joined to a cylinder. The lower thrust structure is attached to the aft gimbal by bolts and to the pressure vessel by means of a quick disconnect.

The gimbal assembly is located between the upper and lower thrust structures. The pump suction line cools the gimbal without creating a significant temperature rise in the fluid. The gimbal assembly has the capability of being actuated over a four degree angle in any direction.





# THRUST CHAMBER ASSEMBLY

- DESCRIPTION

STAINLESS STEEL TUBE BUNDLE  
CAST ALUMINUM JACKET

- EXPERIENCE

TYPE	NUMBER	AREA RATIO
KIWI	2	4:1
HYBRID	2	4:1
NERVA	1	4:1
REACTOR BACKUP	2	4:1
NRX-A	7	10:1

- HOT BLEED PORT TESTS

- PRESSURE VESSEL

ALUMINUM  
TITANIUM



## NERVA ENGINE CONTROL SYSTEM

The five primary control functions required in the NERVA engine are the flux-level control, the core-exit-gas-temperature control, the chamber pressure control, the cooldown control, and the attitude control.

The reactor flux-level control loop consists of neutron sensors, amplifiers, reactivity-control drums, and control-drum actuators. The control-drum actuators are servo subsystems and, as such, constitute an inner loop of the flux loop, since control-drum position is fed back to the actuator servo valve to control the drum position.

The temperature-control loop consists of thermal probes, amplifiers, and compensation, which provides a continuous command signal to the reactor flux loop.

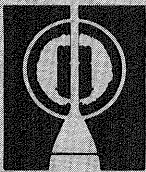
The chamber pressure control loop consists of pneumatic actuators, turbine throttle, pressure transducers, electronic compensators, and signal amplifiers. The turbine power control valve actuator and amplifier which has undergone extensive testing including irradiation is shown on the opposite page.

The cooldown-control loop consists of a cooldown control valve, amplifier, switching circuits, and thermal probes. The turbopump system is bypassed by the cooldown valve and the cooldown control operates off tank pressure.

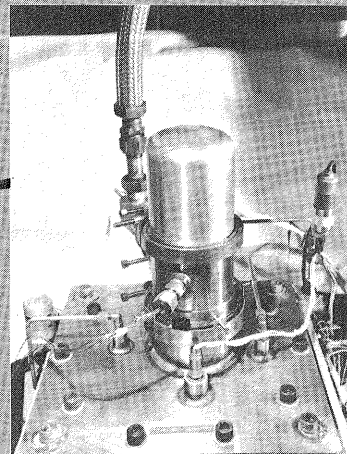
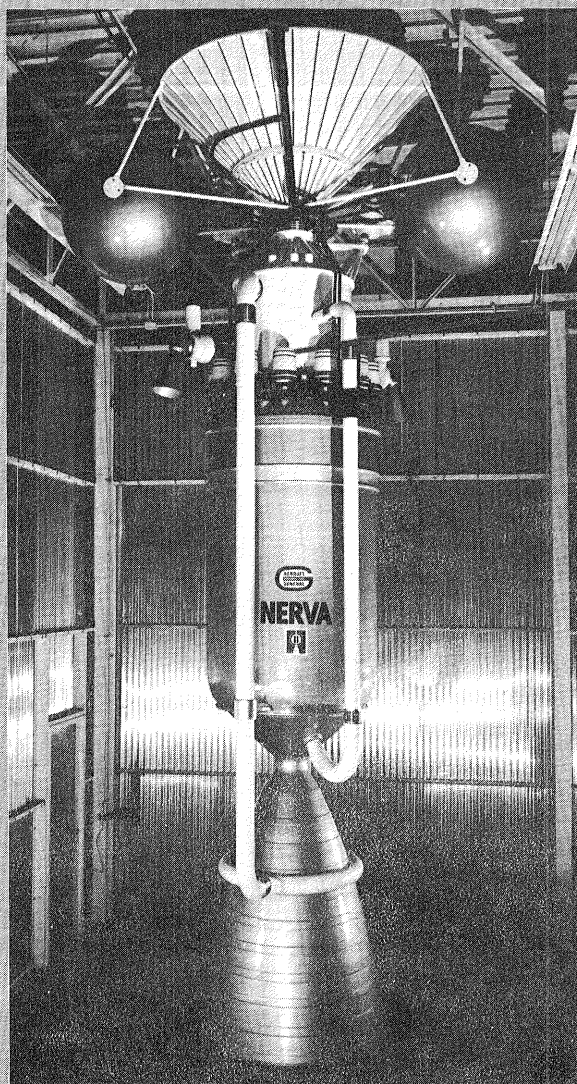
The engine programmer is comprised of reference generators, sequencers, amplifiers, logic circuits, malfunction circuits, timers, and registers. The programmer provides the sequencing logic necessary for the steady-state and transient conditions of the engine system.

The attitude control is made up of amplifiers, servo actuators, a gimballed engine, and roll nozzles, which, when combined with the vehicle guidance system, will perform the desired control function.

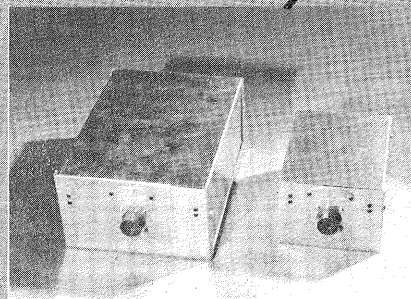




## CONTROLS SYSTEM



- ACTUATORS  
106 HOURS TESTING  
5 HOURS AT 140°R

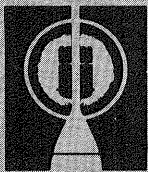


- MAGNETIC AMPLIFIERS  
CRITERIA— $1.0 \times 10^{15}$  nvt FOR ONE HOUR  
TESTED TO  $1.5 \times 10^6$  nvt IN GRT GD/FW

NUCLEAR ROCKET TEST FACILITIES AND  
REMOTE HANDLING EQUIPMENT  
NUCLEAR ROCKET DEVELOPMENT STATION

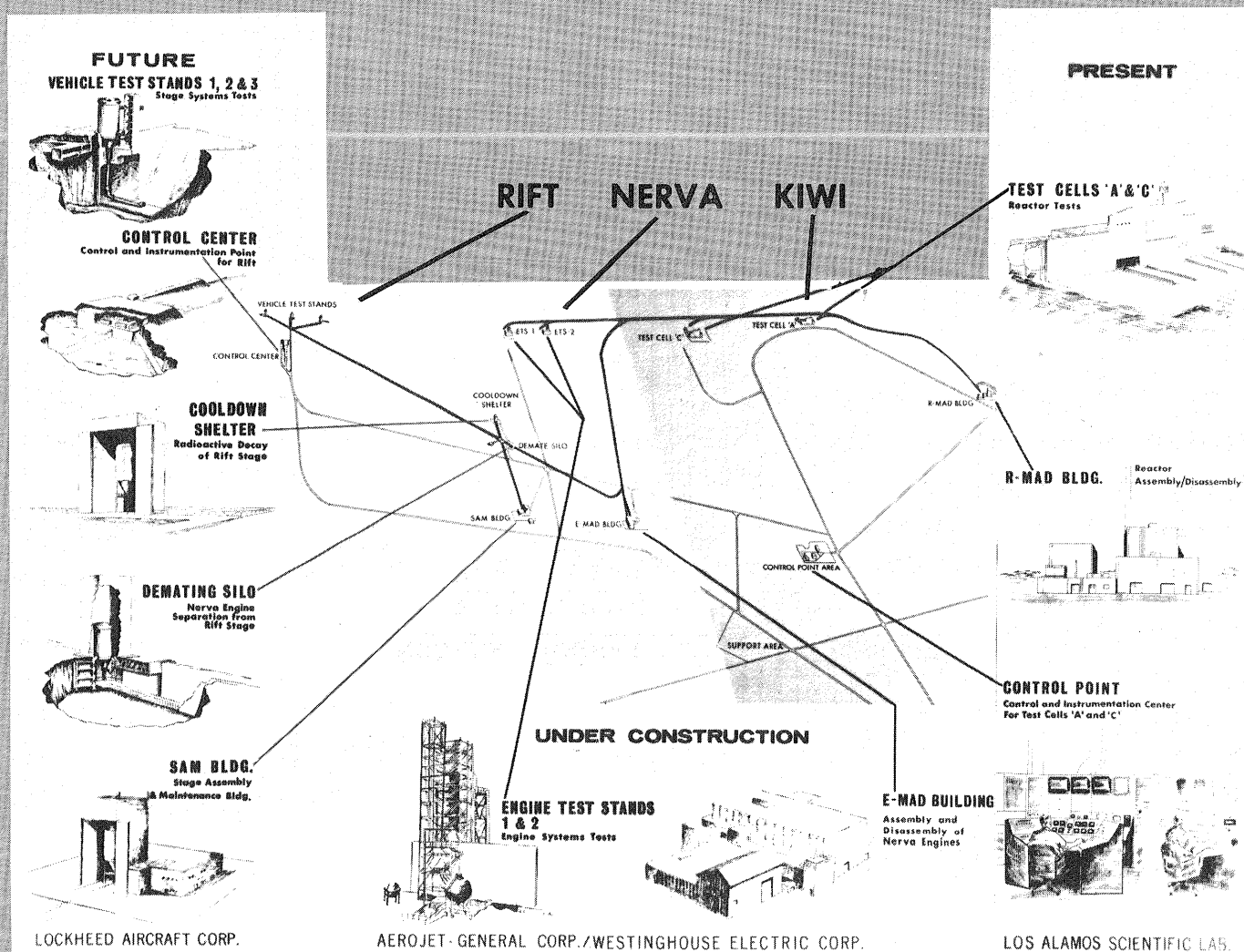
A general facility location plan at the Nuclear Rocket Development Station, Jackass Flats, Nevada, is shown on the opposite page. This shows the Kiwi test area and facilities in use for some time; the NERVA test area and facilities, now under construction; and the RIFT area, whose facilities are to be designed and built in the future.





# NUCLEAR ROCKET DEVELOPMENT STATION

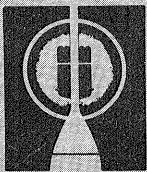
## (Project Rover)



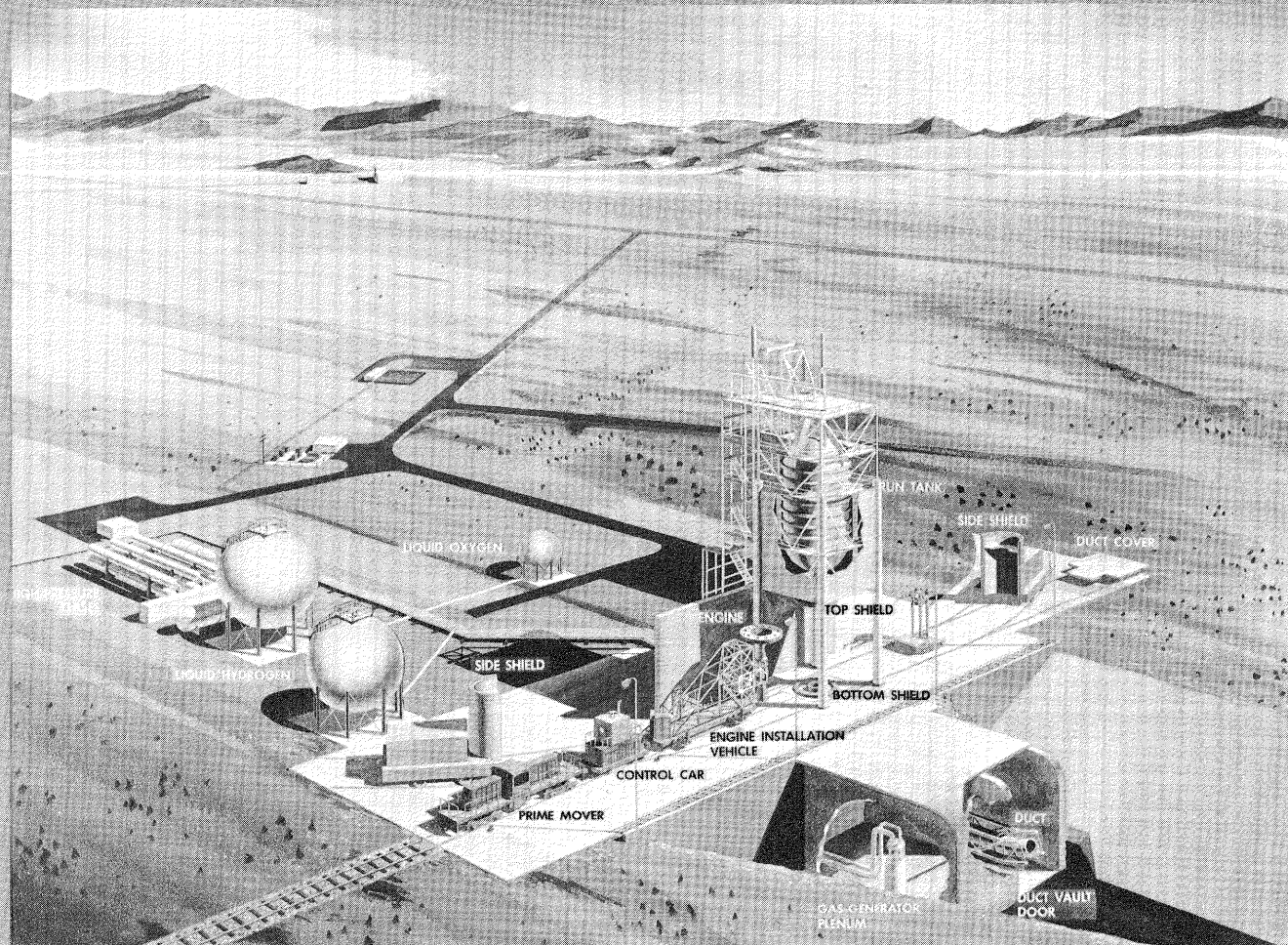


### ENGINE TEST STAND ETS-1

One of the most complex of the installations is the Engine Test Stand (ETS), an artists' concept of which is shown on the facing page. The stand superstructure rises approximately 140 feet above the track deck, and the vault containing the exhaust duct is 55 feet deep. Also shown is the transport/installation system, various propellant and pressurant tanks and various other items of facility support equipment and structure.



# ENGINE TEST STAND ETS-1



### ETS-1 CONSTRUCTION PROGRESS

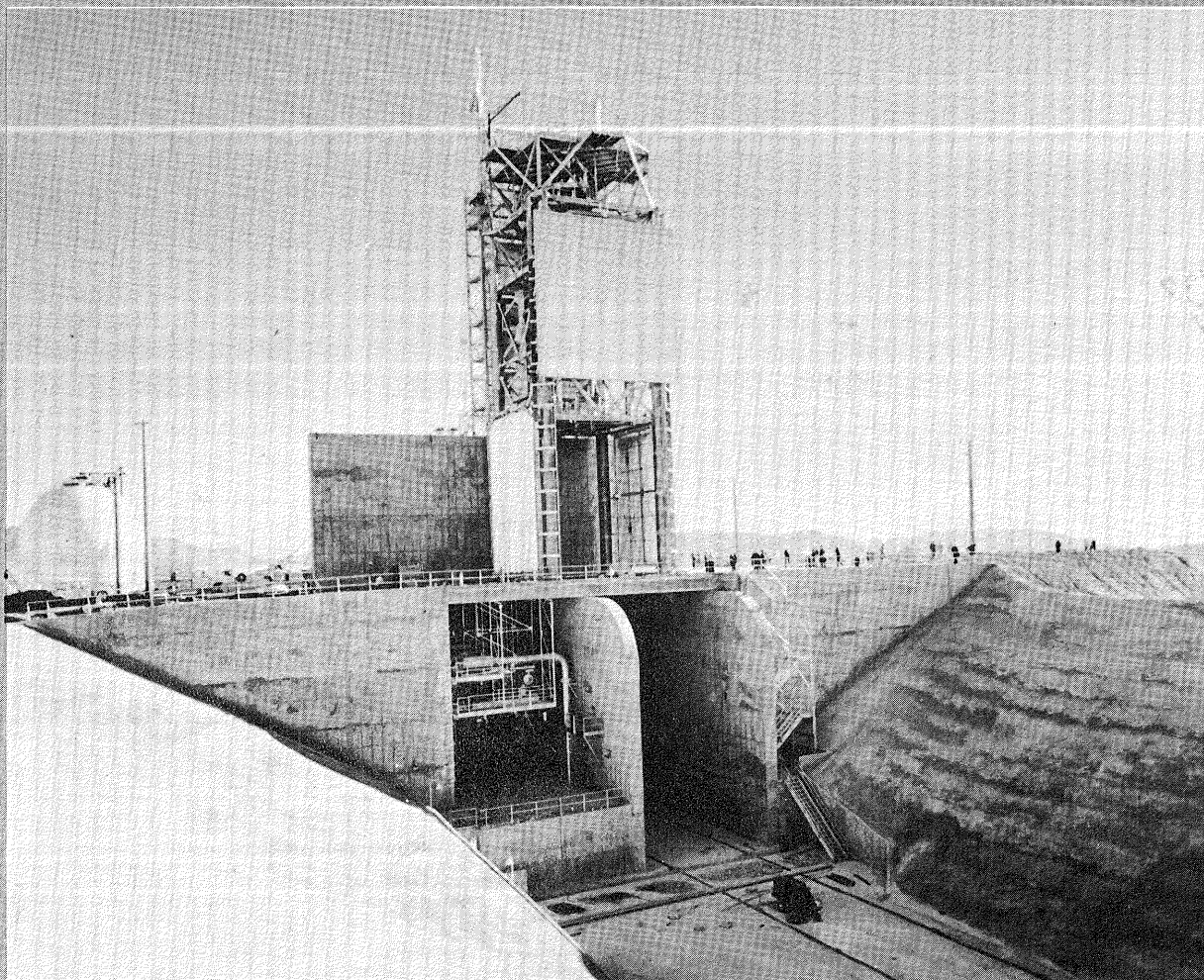
Ground was broken for this facility in June 1961, one month before the NERVA contract was awarded. While the civil works are largely completed, as shown in the photograph, approximately two additional years will be required to provide the facility instrumentation, the engine test control devices and to complete activation and check-out.





# **ENGINE TEST STAND ETS-1**

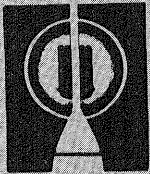
## **Construction Progress**



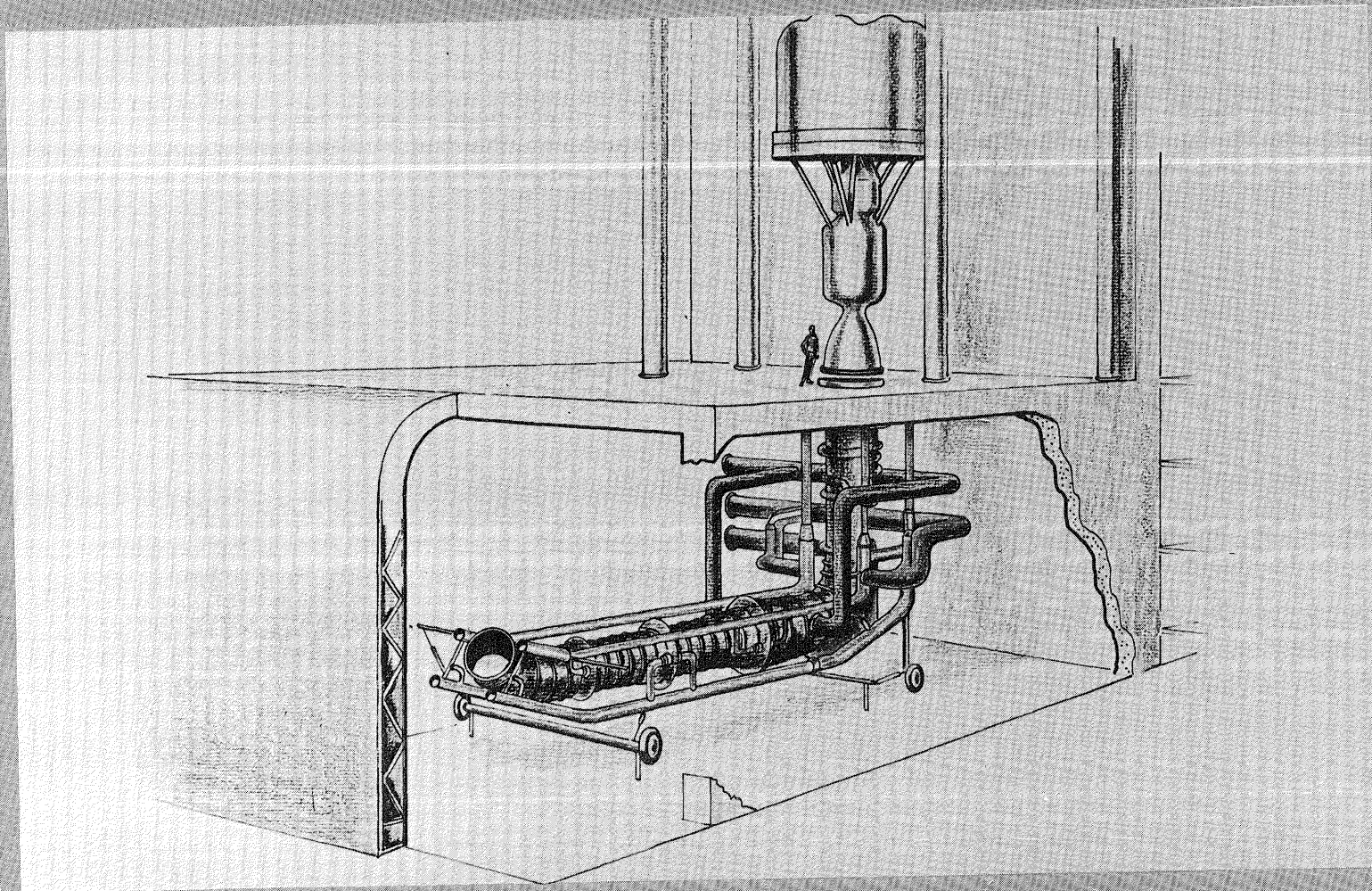
### NERVA EXHAUST SYSTEM

One concept for the exhaust duct is shown on the opposite page. Exhaust duct configurations have been designed and some scale-model testing performed. Design work is expected to be completed before the end of the year, with about one year required for fabrication and installation. The duct is required to dispose of the high temperature hydrogen exhaust gas which has been subjected to the radiation environment of the reactor. Because of the temperature of the exhaust gasses, the duct must be cooled, and the flow and heat transfer characteristics present a challenging design problem.





# NERVA EXHAUST SYSTEM



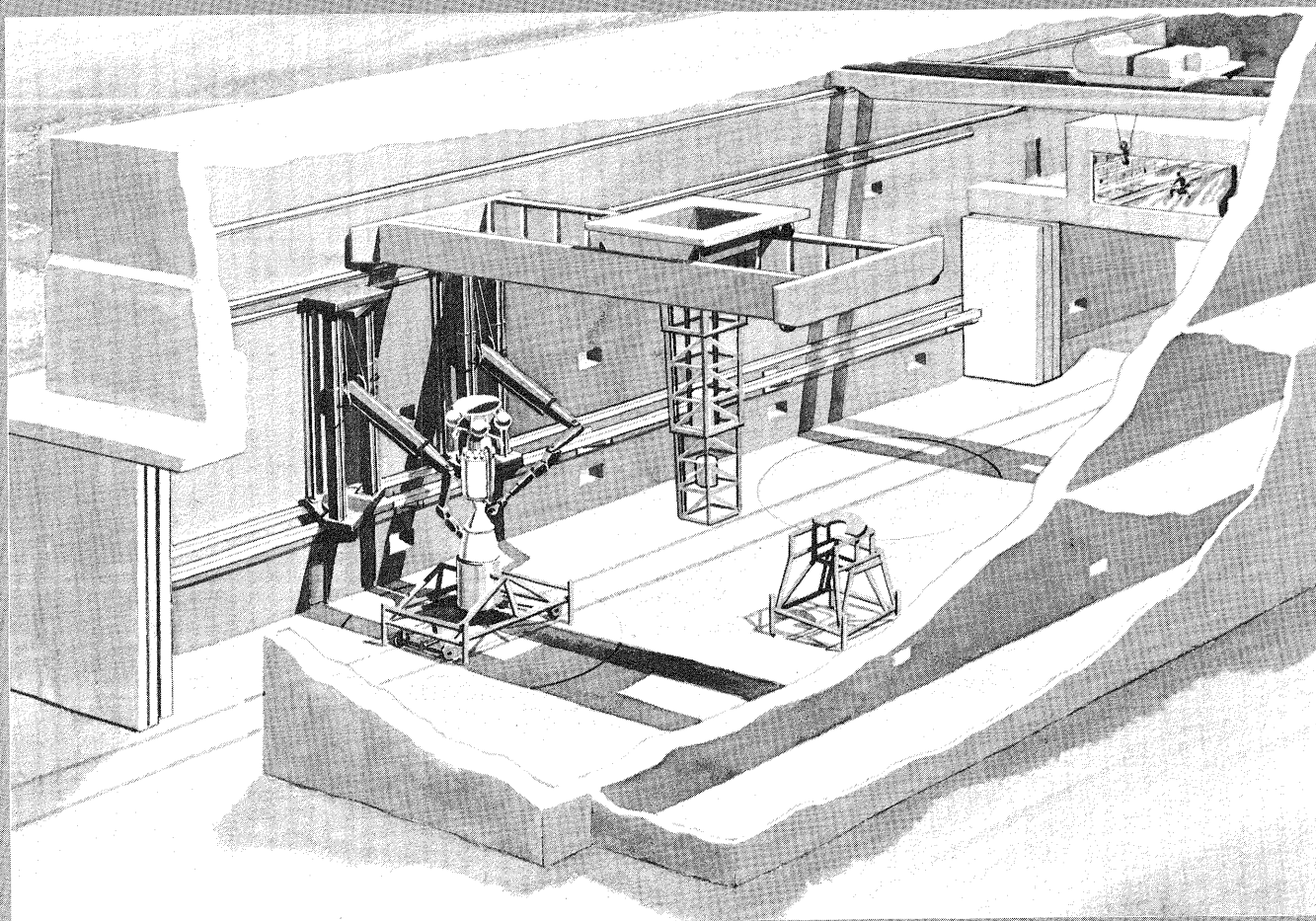
#### ENGINE MAINTENANCE ASSEMBLY/DISASSEMBLY (E-MAD) BUILDING

Another significant facility is the Maintenance Assembly/Disassembly Building shown on the opposite page. The non-nuclear engine assembly will be delivered to NRDS from Aerojet's Sacramento plants and the reactor system will be delivered from the Westinghouse Astronuclear Laboratory in Pennsylvania. The engine will be assembled in the E-MAD building and moved to and installed in the test stand by the transport/installation system. Shown in the building cutaway are the wall-mounted manipulators, the overhead positioning system, and various floor-mounted handling fixtures. Major disassembly of the engine following a test will occur in the large "hot" area. Engine subassemblies and components are disassembled in a series of satellite cells located around the main disassembly area.





## E-MAD BUILDING



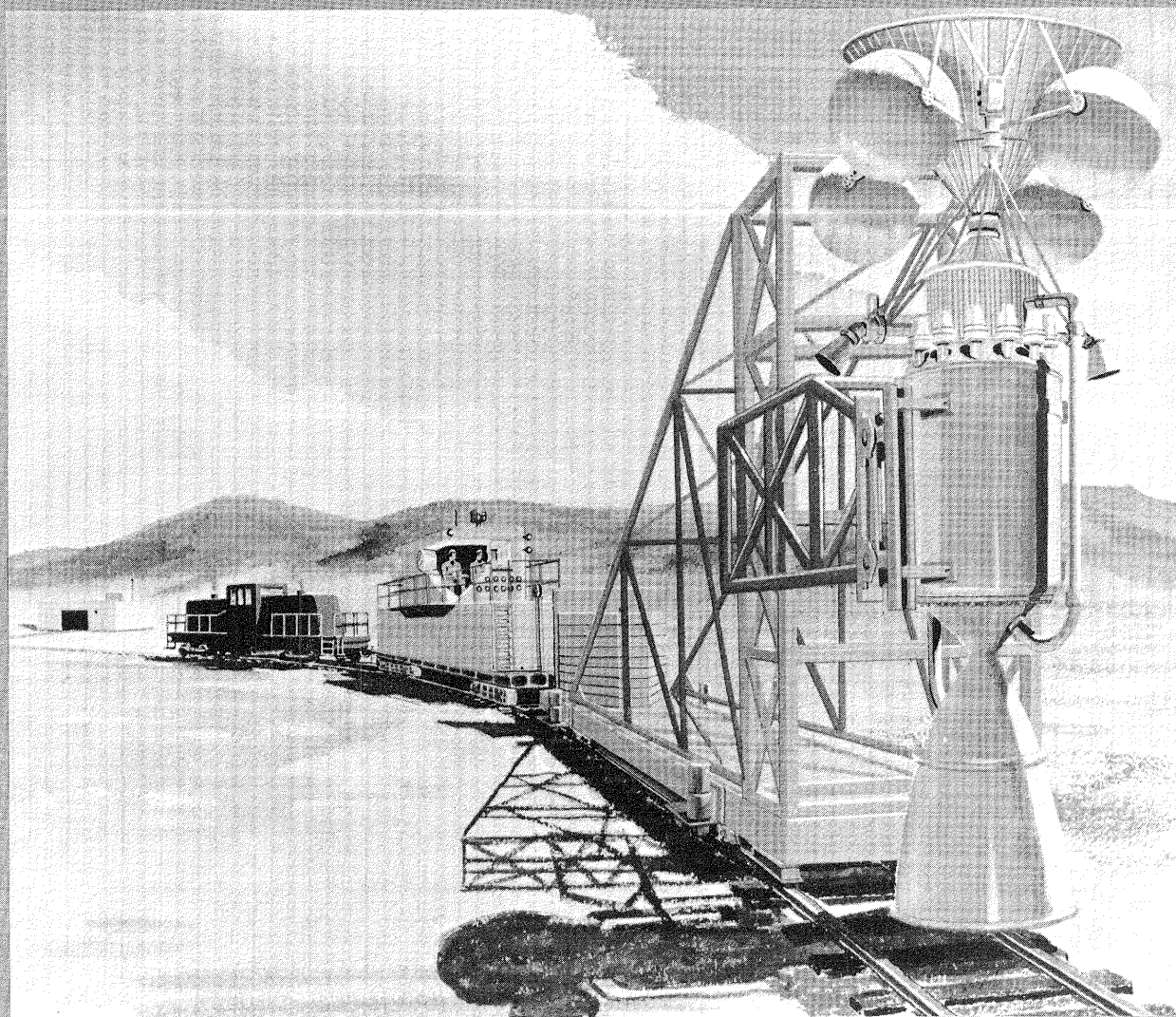


### NERVA TRANSPORT INSTALLATION SYSTEM

An artist's concept of the system used to transport the engine to and from the test stand is shown on the accompanying figure. .It consists of the engine installation vehicle, the shielded manned control car and the prime mover. The assembled engine is mounted on the installation vehicle in the E-MAD building, transported to the test stand and remotely installed into the test stand under the control of the personnel in the control car. Following a test, the engine is remotely disconnected from the stand, returned to the E-MAD building for disassembly and post mortem inspection.



# **ENGINE TRANSPORT INSTALLATION SYSTEM**



NON-NUCLEAR TEST FACILITIES  
AT THE AEROJET SACRAMENTO PLANT

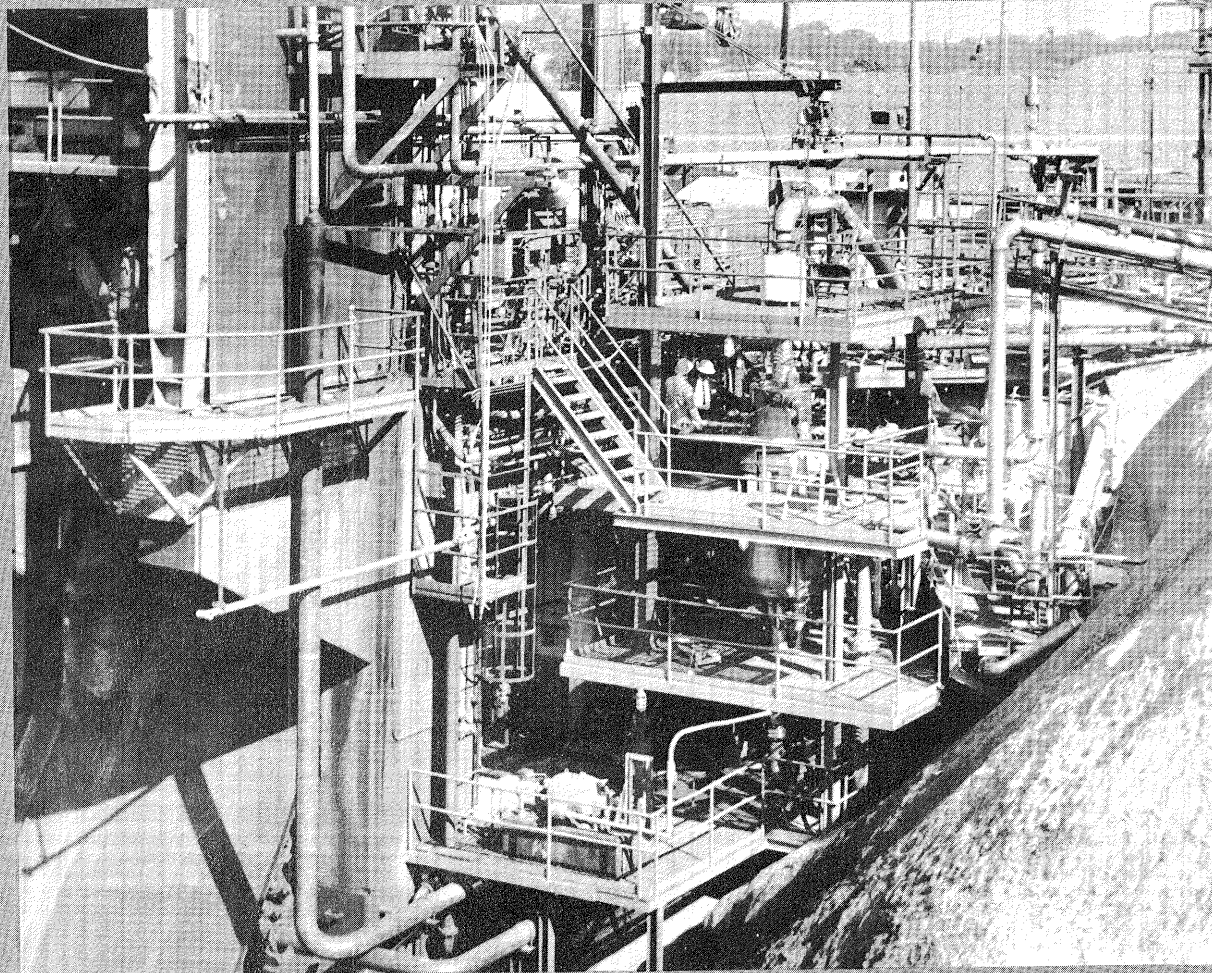
The following figures are photographs of the special facilities that have been built to support the non-nuclear engine development test program at Sacramento. The first is a photograph of the modifications that have been made to one of the Titan test stands to accommodate NERVA turbopump development and engine simulator test program. The recently built liquid hydrogen run tank for non-nuclear engine system development in another Sacramento test area is shown in the second figure. The new engineering cryogenic laboratory is shown in the last figure. It will be used for the development of various cryogenic feed system components and tests of the hydrogen cooled bearings.



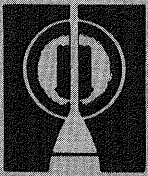


# **TEST ZONE C**

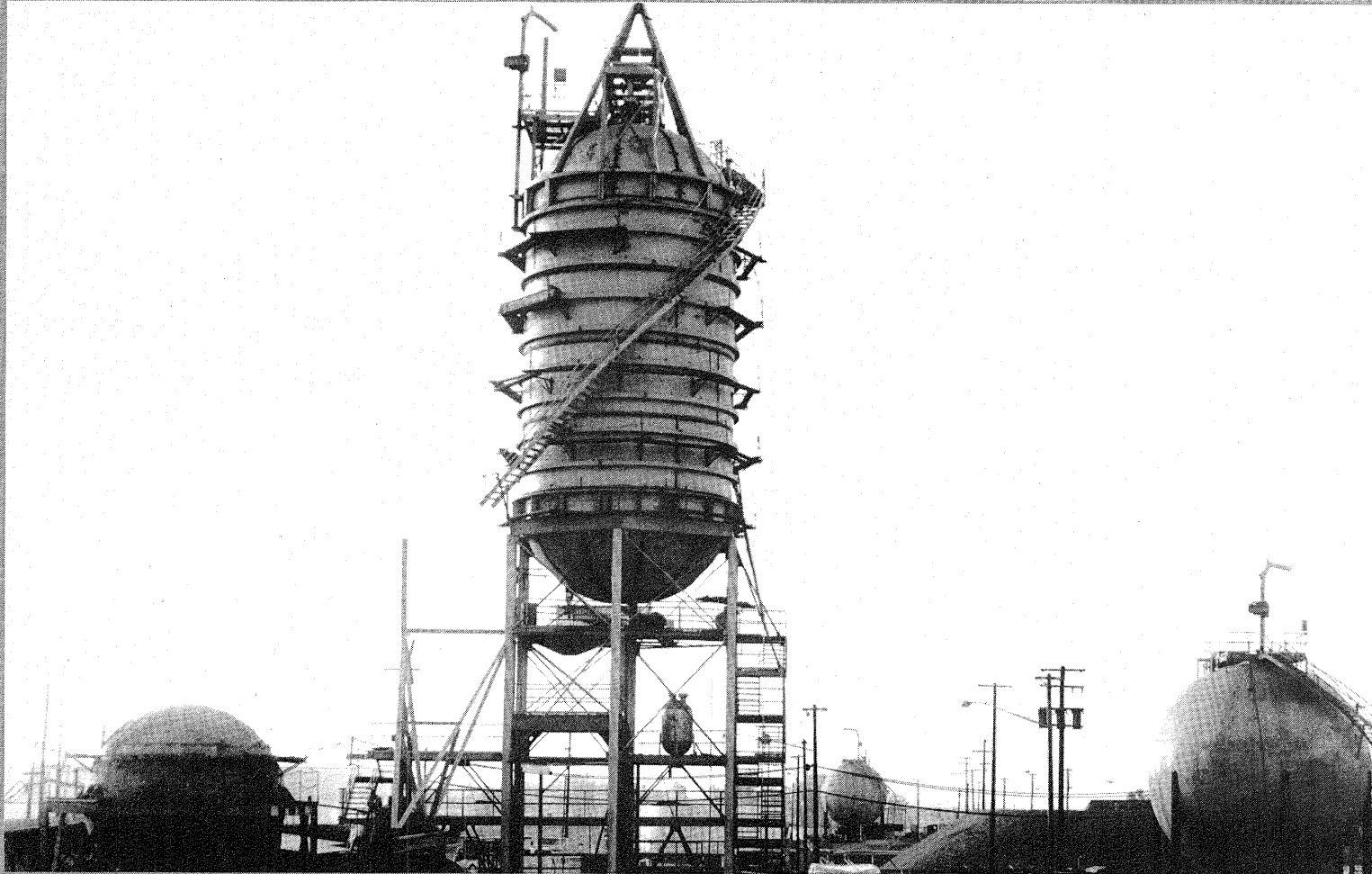
## **Test Stands C-7, 8**



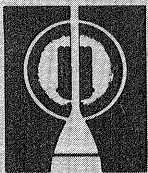




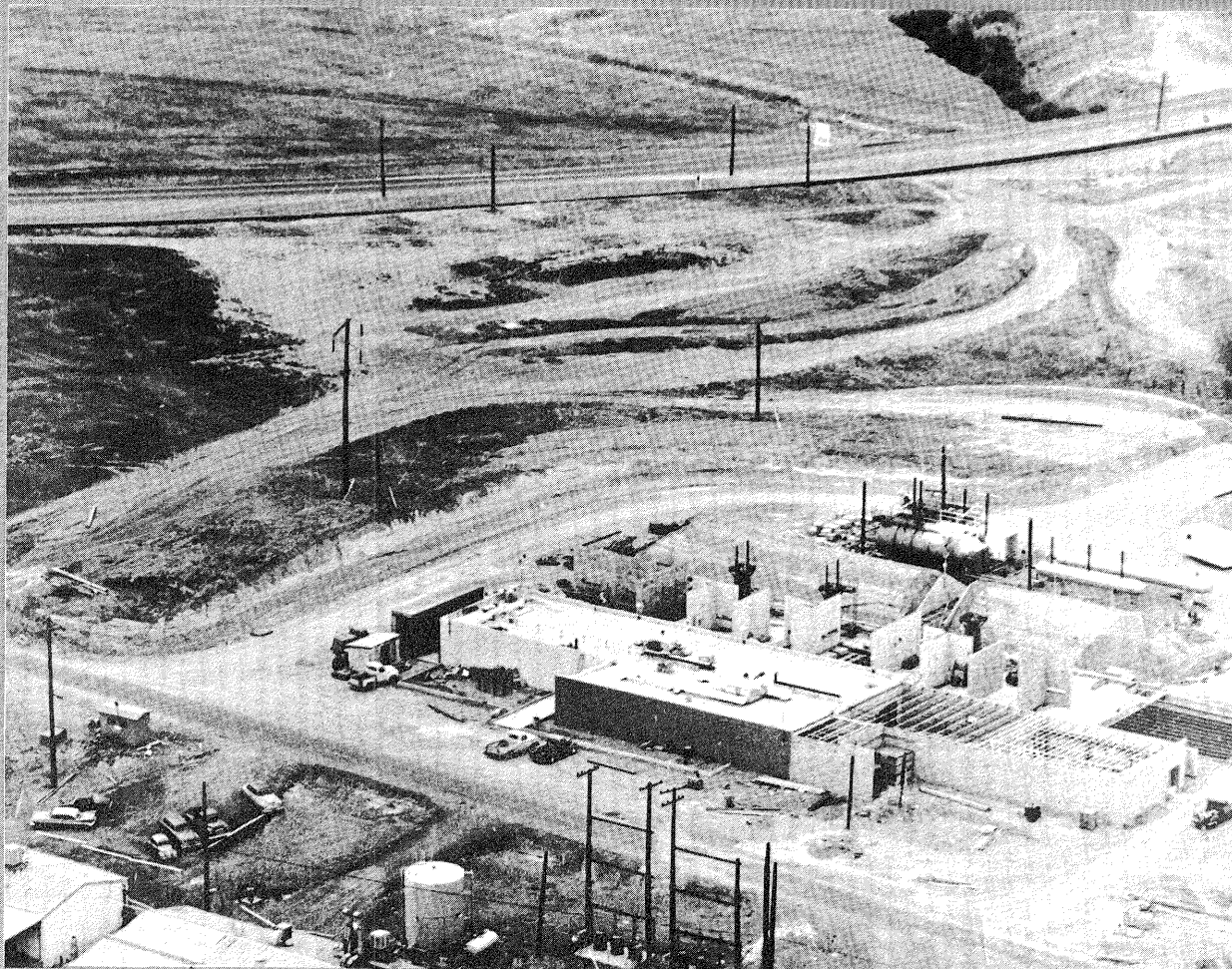
## **TEST ZONE H**







# **CRYOGENICS LABORATORY**

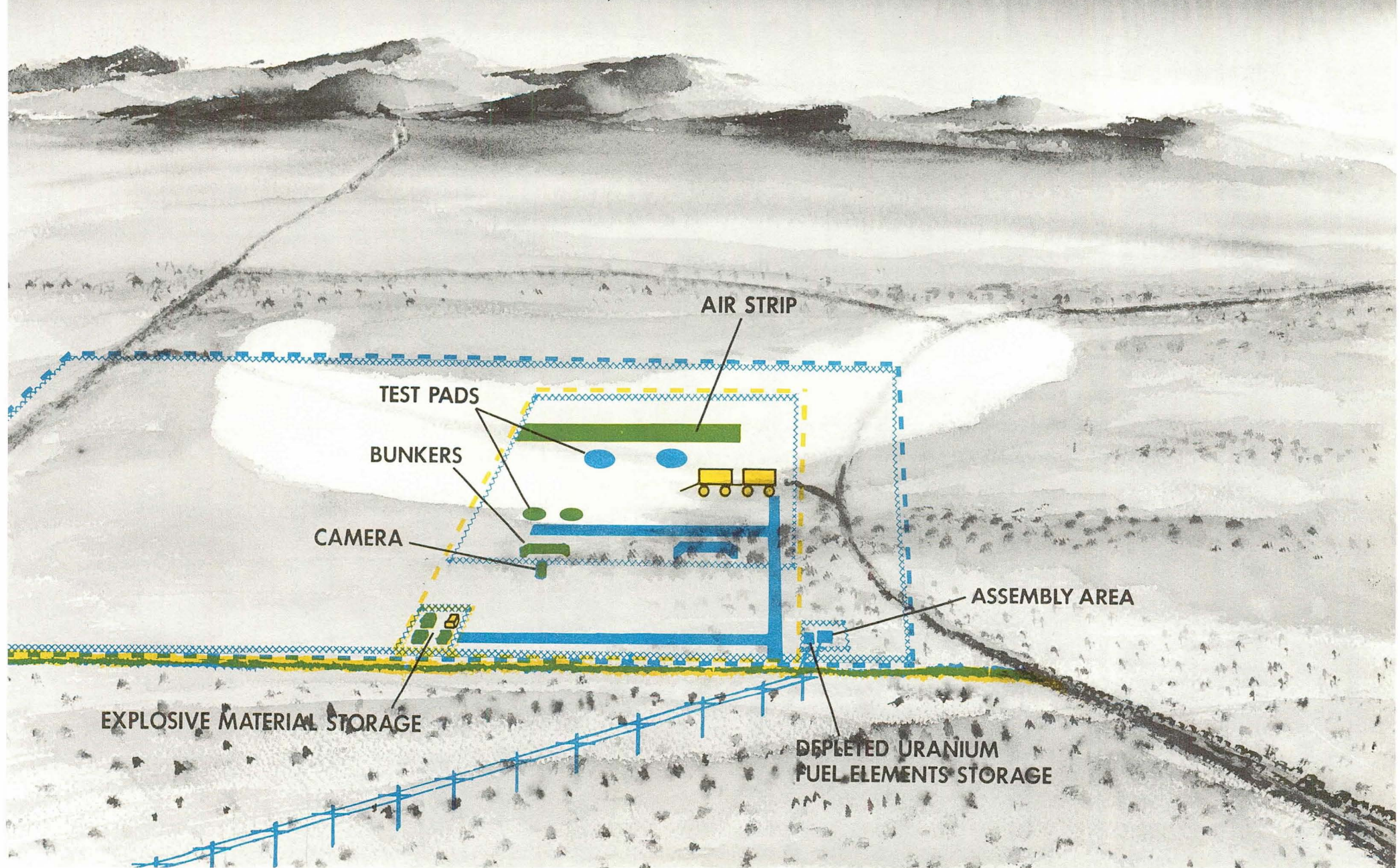


#### NERVA DESTRUCT SYSTEM FACILITY

A site plan of the destruct system test area at Hawthorne, Nevada is shown in the accompanying figure. A number of destruct system tests have already been conducted in this area and additional facility installations will permit more thorough evaluation of the various destruct system concepts.



## HAWTHORNE, NEVADA TEST FACILITY



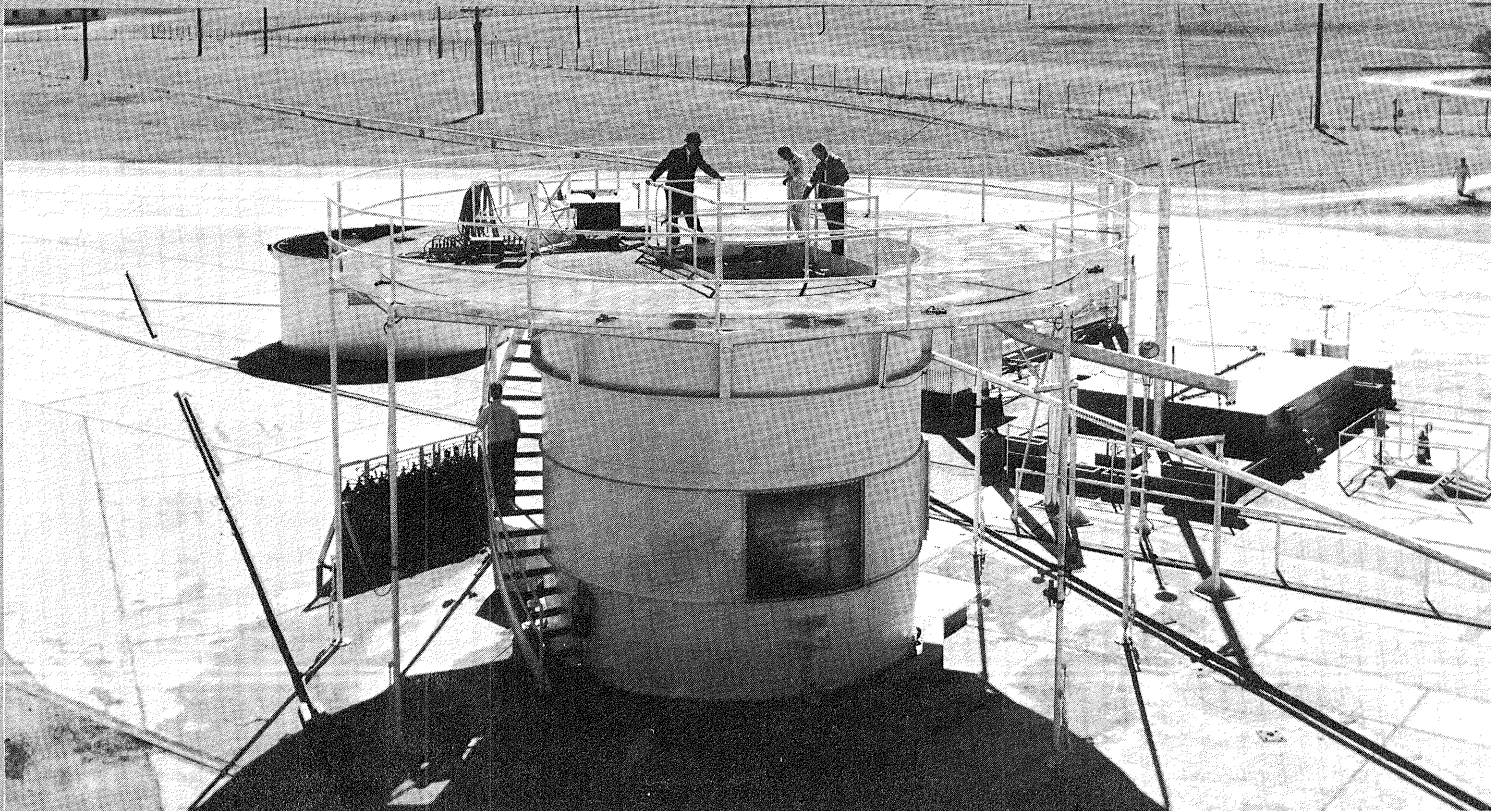


### RADIATION EFFECTS FACILITY

One of the unique development problems associated with the NERVA engine development is the behavior of materials and certain engine sub-systems and components in the combined radiation and cryogenic environment. While there is a fairly extensive background of the separate effects, only extremely limited data has been obtained for the combined case. An extensive radiation effects program has been instituted. Typical of the facilities that are being used is the ASTR reactor shown in the figure, located at General Dynamics, Fort Worth. Typical of other facilities that probably will be utilized are the Plumbrook, Vallecitos, and Western New York research reactors.



## ***RADIATION EFFECTS FACILITIES***



- **ASTR—GENERAL DYNAMICS/FORT WORTH**
- **PLUM BROOK—NASA**
- **VALLECITOS ATOMIC LAB—GENERAL ELECTRIC**
- **WESTERN NEW YORK RESEARCH CENTER**



### OPERATIONAL NERVA-CLASS ENGINES

Despite the immediate goals of the NERVA program to demonstrate the feasibility of a nuclear rocket performing safely and reliably in the space environment, it has been realized by all that the ultimate objective of the development must be in the application of the concept to missions of national interest. It is with this in mind that the present study of operational NERVA-class engines for application to the lunar logistic system has been undertaken. Certain mission-directed requirements have been imposed, and certain engine dictated constraints have been applied. The ground rules, guidelines, definitions and performance characteristics are shown in the following figures.



# ENGINE MODEL DEFINITION

## MOD 0 RIFT TEST ENGINE

MOD 1

P 1120  
T 56100  
ISP 763

ReStart - 0  
FIRING Length 1200  
Pc - 550

MOD 1a EARLY OPERATIONAL ENGINE WITH NERVA POWER LEVEL AND EXTENDED FIRING DURATION AT RATED CONDITIONS WITH NO RESTART REQUIREMENT

MOD 1b SAME AS MOD 1a EXCEPT ONE RESTART IS REQUIRED

MOD 2a FULLY OPERATIONAL ENGINE WITH IMPROVED SPECIFIC IMPULSE AND NO RESTART REQUIREMENT

MOD 2b SAME AS MOD 2a EXCEPT ONE RESTART IS REQUIRED

MOD 3a FULLY OPERATIONAL ENGINE WITH IMPROVED SPECIFIC IMPULSE, HIGHER THRUST, EXTENDED FIRING DURATION AND ONE RESTART REQUIREMENT

MOD 3b SAME AS MOD 3a EXCEPT TWO RESTARTS ARE REQUIRED

1271 P  
62540 T  
790 ISP  
4300 T  
600 Pc  
2100 sec FT  
1 Re Start





# **GROUND RULES FOR ENGINE MOD SELECTION**

- **MOD 0**

**RIFT TEST ENGINE**

- **MOD 1**

**MOD 0 ENGINE WITH EXTENDED FIRING DURATION**

- **MOD 2**

**GROWTH POTENTIAL WITHIN PRESENT NERVA DESIGN FOR IOC\***

**NO MODIFICATIONS REQUIRED**

- **MOD 3**

**GROWTH POTENTIAL WITHIN PRESENT REACTOR DESIGN FOR IOC\***

**NEW TURBOPUMP ASSEMBLY**

**NEW THRUST STRUCTURE AND GIMBAL**

**NEW REACTOR PRESSURE VESSEL**

**NEW PROPELLANT LINES**

**\*Initial Operational Capability**





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**PERFORMANCE RATING\***  
**Operational Nerva Engine (u)**

	MODEL NUMBER						
	0	1		2		3	
		a	b	a	b	a	b
● NEUTRON POWER (mw)	1120	1120	1120	1271	1271	2020	2020
● THRUST, ENGINE (lb)	56,100	56,100	56,100	62,540	62,540	101,865	101,865
● SPECIFIC IMPULSE, ENGINE (lb-sec/lb)	763	763	763	790	790	779	779
● THRUST, CHAMBER (lb)	54,600	54,600	54,600	60,500	60,500	97,200	97,200
● SPECIFIC IMPULSE, CHAMBER (lb-sec/lb)	780	780	780	810	810	810	810
● CORE EXIT GAS TEMPERATURE (°R)	4090	4090	4090	4300	4300	4300	4300
● CHAMBER PRESSURE (psia)	550	550	550	600	600	1000	1000
● CHAMBER WEIGHT FLOW RATE (lb/sec)	70	70	70	74.5	74.5	120	120
● PUMP WEIGHT FLOW RATE (lb/sec)	74.1	74.1	74.1	79.8	79.8	132	132
● TURBINE WEIGHT FLOW RATE (lb/sec)	3.5	3.5	3.5	4.7	4.7	10.75	10.75
● TURBINE INLET GAS TEMPERATURE (°R)	1760	1760	1760	1770	1770	1800	1800
● ENGINE WEIGHT (lb)	16,149	16,149	16,149	16,149	16,149	17,050	17,050
● FIRING DURATION (sec)	1200	1200	1500/2100	1200	1500/2100	1500	1800
● MODE OF OPERATION	RIFT BALLISTIC	O.S.	O.S./S.O.S.	O.S.	O.S./S.O.S.	S.O.S.	S.O.S.
● RESTART REQUIREMENT	2	0	1	0	1	1	2

\* NOZZLE AREA RATIO,  $\epsilon = 40:1$

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\* NOZZLE AREA RATIO,  $\epsilon = 40:1$

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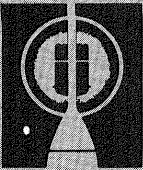
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#### MOD 2 ENGINE DESIGN POINT SELECTION CRITERIA

The Mod 2 engine, defined as having improved specific impulse, is based on an increased reactor core exit gas temperature. Specific impulse can be increased by other methods, i. e., reduced turbine bleed requirements and larger nozzle area ratio. However, the greatest gain is achieved by increasing the chamber temperature. The maximum gas temperature attainable is a function of the reactor thermal stresses. As the reactor heat transfer rate is increased the nozzle hot gas wall temperature becomes the limiting parameter. A hot gas wall temperature of 1950°R is the accepted design value for the NERVA nozzle. The accompanying figure presents the results of an optimization study to define the Mod 2 engine. This figure is a plot of hot gas wall temperature vs chamber pressure for constant values of chamber temperature. The upper constraint is a result of the nozzle material temperature limitations, whereas the right boundary represents the pump flow constraint. Based on these limitations a chamber temperature of 4300°R was selected for the Mod 2 engine, as an initial value obtainable with experience in fuel element fabrication.

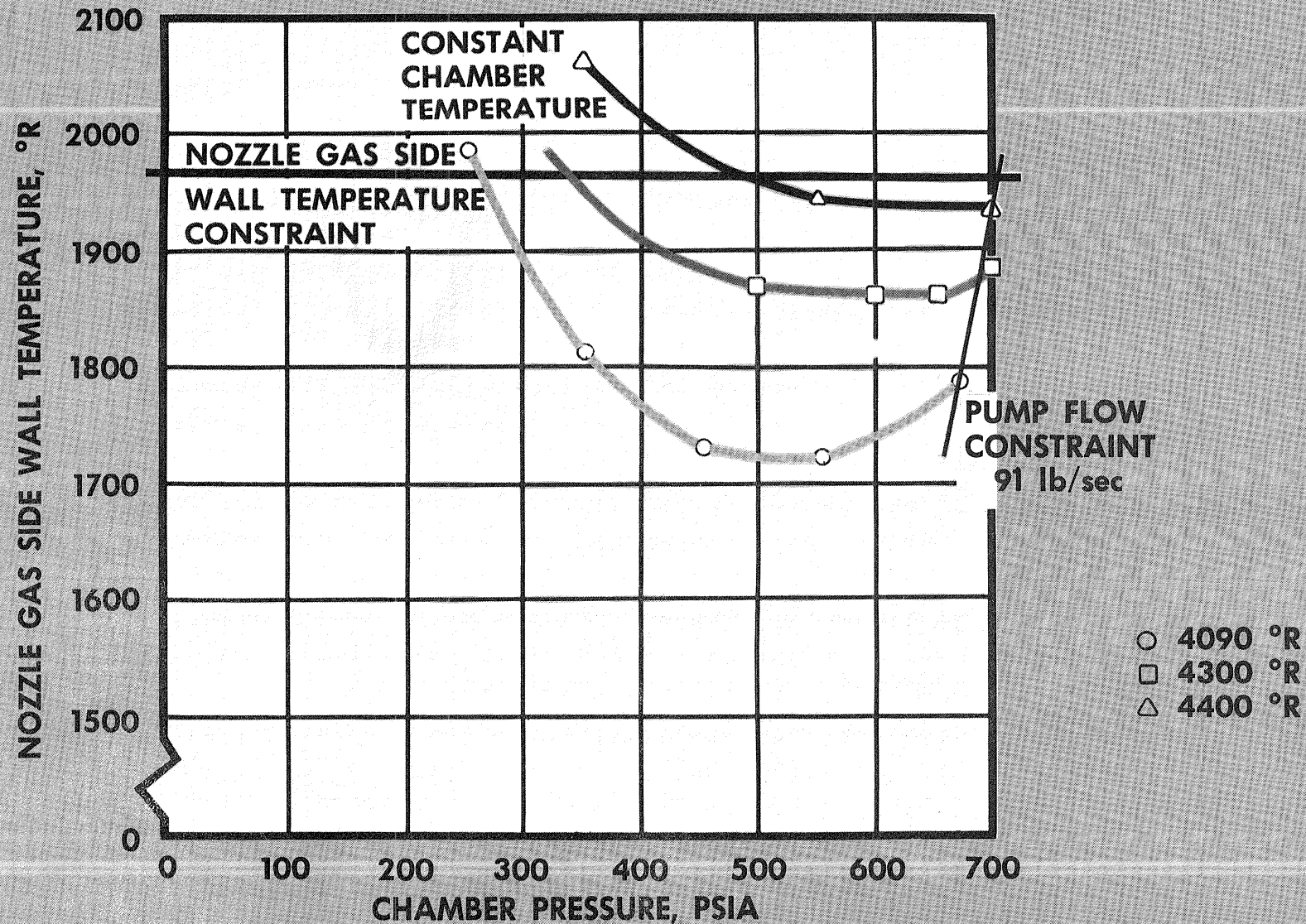
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## CRITERIA FOR MOD 2 DESIGN (U)



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#### ENGINE OPERATING MAP WITH COMPONENT CONSTRAINTS

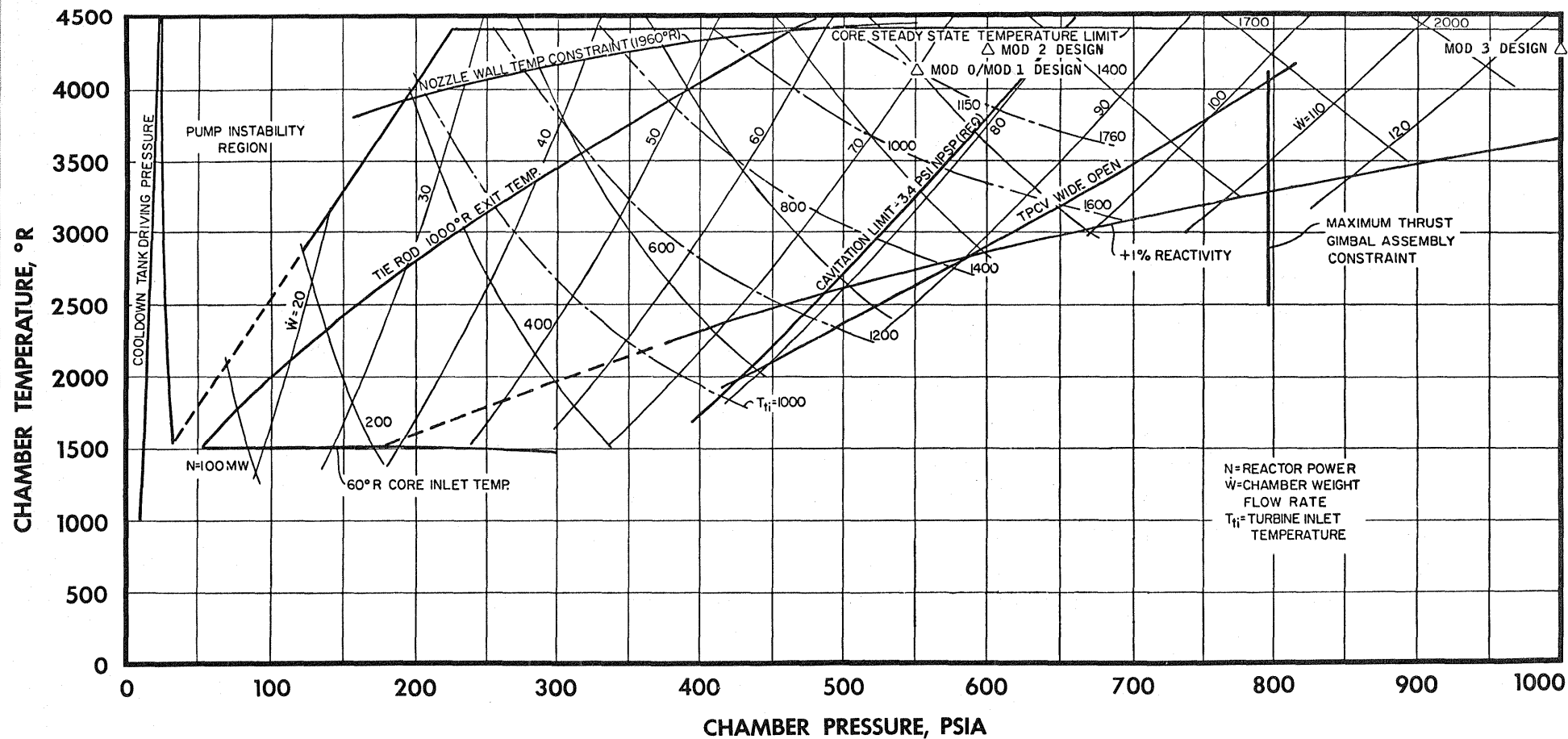
Unlike a chemical rocket engine, the NERVA engine is capable of steady-state operation over a wide range of conditions. The complete steady-state operating map is shown which presents reactor power and exhaust nozzle weight flow rate as a function of core exit gas temperature and nozzle exhaust pressure. The system parameters, both dependent and independent, required for operation at any steady-state off-design operating point are thus defined. Also indicated are the design operating points for the Mod O/Mod 1, Mod 2 and Mod 3 engines. What is particularly significant in this figure, however, is the limitations on engine operation. These limits are crucial since they determine the possible bounds of engine operation. The first limitation is that imposed by the cool-down tank driving pressure. The region of pump instability was plotted based on the minimum specific speed as defined by pump development tests. Two limits on core exit gas temperature, one based on the maximum steady-state core temperature limit of 4300°F and the other on the transient core temperature limit of 4500°R. The component which limits the axial load carrying capability of the overall thrust structure is the gimbal assembly. This component is designed to operate at a maximum thrust load of approximately 84,000 lb. The upper and lower thrust structures, however, have the capability to withstand thrust loads up to approximately 450,000 lb. The last limitation on engine operation is the fluid temperature into the core as set by the requirement that no liquid hydrogen enter the core, since this could create local uncontrollable excess reactivity.

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## ENGINE OPERATING MAP WITH COMPONENT CONSTRAINTS



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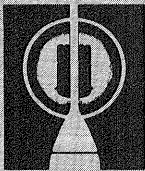
#### ENGINE COOLDOWN

It is currently planned that during engine cooldown, flow is controlled to maintain reactor temperature in the range of 1800 to 2000°R. Present calculations indicate that to maintain flow stability in the core flow passages, a minimum flow rate of approximately 2.5 lb/sec is required. For the accepted tank pressure of 25 psia, a flow rate of 3.3 lb/sec is available for afterheat cooling. This is sufficient to handle a power level of 25 mw with a core exit gas temperature of 2000°R. This is considered to be the limiting temperature due to conductive and radiant heat transfer which could result in subjecting some structural components to excess temperature. However, since this flow rate would cool the reactor too fast, a pulse cooling technique is tentatively planned.

Since the time at full power operation affects the heat generation rates, the engine cooldown schedule will vary for the various engine modes. In the following figure, a typical cooldown schedule for the Mod 1 engine after 1200 sec operation at rated conditions is shown. Also listed on the figure are the number of pulses required and the propellant consumption during a 72 hour vehicle coast period.

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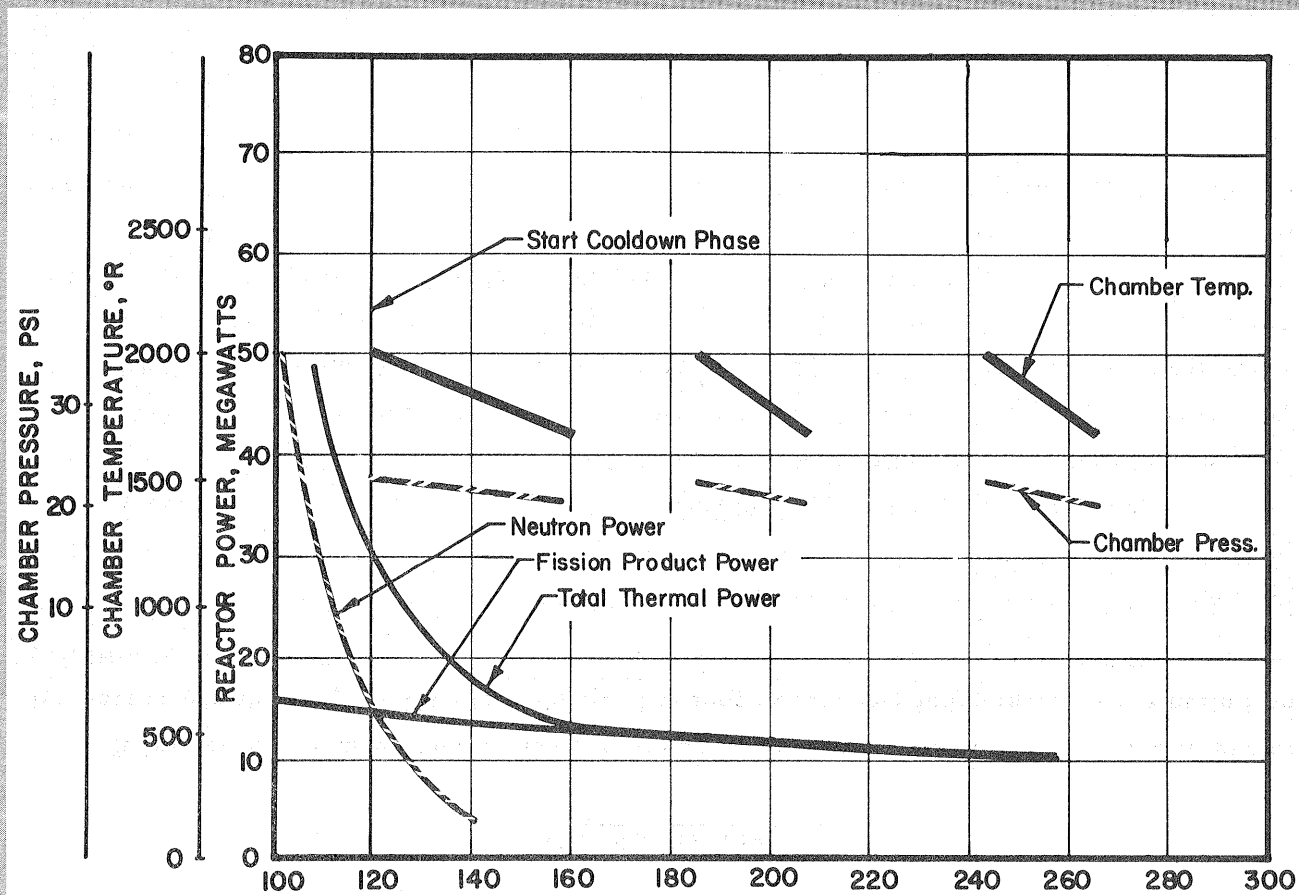
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## TYPICAL COOLDOWN SCHEDULE (U) Mod 1b Engine



FOR 72 HR COAST PERIOD FOLLOWING 1200 SEC.  
OPERATION AT POWER, 37 COOLING PULSES REQUIRED  
WITH NET PROPELLANT CONSUMPTION OF 10,350 LB.

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#### ENGINE DEVELOPMENT SCHEDULE

A development schedule, representing the best estimate of future events, is presented in the accompanying chart. Because of the reactor mechanical design problem, there is no engine development schedule included in the official NERVA program planning documents, the emphasis through 1965 being placed on reactor development. However, based on successful reactor demonstration, the first engine test could be conducted early in 1966, followed by initiation of PFRT in 1968, first flight in 1970, and a first operational flight in 1972. The various operational NERVA engine modes will each require analysis to determine the effects of the various development complications on the overall engine development program.

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# **TYPICAL ENGINE DEVELOPMENT SCHEDULE**

## **MOD 1**

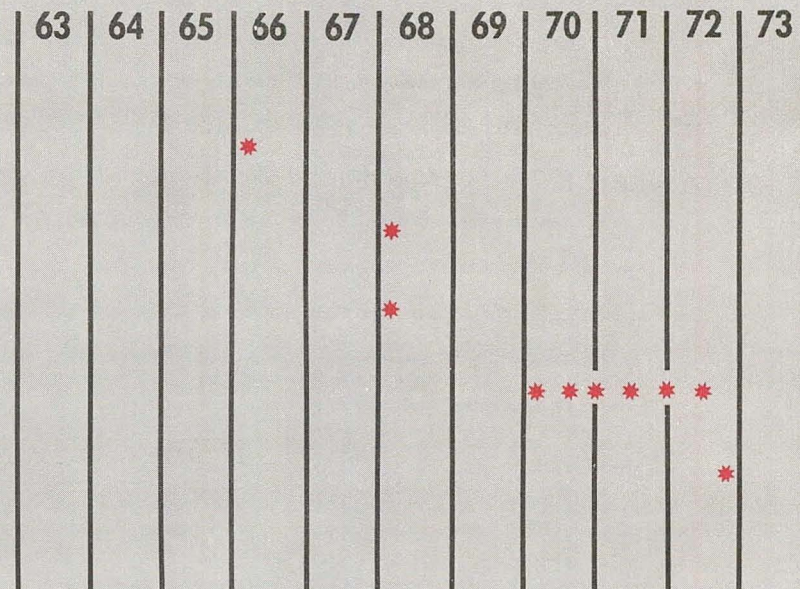
FIRST DEVELOPMENT TEST

ENGINE DELIVERY FOR STAGE DEVELOPMENT

FIRST PFRT

FLIGHT TEST

FIRST OPERATION FLIGHT

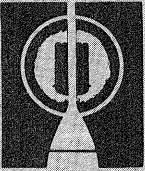


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### SUMMARY AND CONCLUSIONS

Figures presented in this document have been prepared to describe the general status of the NERVA engine development program, and to define the characteristics of several operational NERVA-class engines. The definition of the operational engines is to be considered preliminary with further refinements to be provided after additional analysis, design and evaluation. In addition, data regarding engine development schedules, engine development, program costs and engine unit costs will be prepared. Effort will be expended to examine thoroughly the possibility of reduction in engine weight. The startup, shut-down and cool-down operations require special attention. Finally, considerable data will have to be provided in all technical and programmatic areas for inclusion in the final summary report considering this study.



## ***SUMMARY AND CONCLUSIONS***

- PRELIMINARY DEFINITION OF OPERATIONAL ENGINES COMPLETED
- PREPARE REFINED ENGINE PERFORMANCE DATA
- DEFINE ENGINE TRANSIENT CHARACTERISTICS
- EVALUATE ENGINE COOLDOWN TECHNIQUES
- PREPARE OPERATIONAL ENGINE MODEL SPECIFICATIONS
- EXAMINE ENGINE WEIGHT REDUCTION POSSIBILITIES
- DEFINE REQUIRED COMPONENT R & D
- IDENTIFY ADDITIONAL TEST FACILITY REQUIREMENTS
- DEFINE QUALIFICATION TEST SPECIFICATION
- PREPARE SCHEDULE AND COST INFORMATION





**End of Document**